The 2006 slow slip event and nonvolcanic tremor in the Mexican subduction zone.

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2006 Slow Slip Event and Nonvolcanic Tremor in the Mexican Subduction Zone

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Last decade features an explosive sequence of discoveries of Slow Slip Events (SSE) and Nonvolcanic Tremor (NVT) in different subduction zones and continental faults. Many observations show that SSE is usually associated with an increased NVT activity but it is not clear yet if those events are the result of the same process or are independent expressions of a common underlying seismotectonic source. A large SSE in Central Mexico occurred in 2006 during the Meso-American Subduction Experiment (MASE) which provided continuous observations of the NVT for the 2005-2007 epoch. GPS and abundant seismic data show that although the NVT energy increased notably during the 2006 SSE, the two phenomena were separated spatially and not consistent in time. Significant NVT episodes occur during the period between SSEs, suggesting again that large slow slip events and NVT observed in the Mexican subduction zone may be of different origins. The

results presented here could contribute in an uncovering the nature of these indistinct in many cases natural phenomena.

1. Introduction

There is a growing scientific challenge to understand the origin of the Slow Slip Events (SSE) [*Schwartz and Rokosky*, 2007] and Nonvolcanic Tremor (NVT) [*Obara*, 2002; *Rubinstein et al.*, 2010]. SSE and NVT observed now in different subduction zones may be a very important constituent in the cycle of large subduction thrust earthquakes. Many studies show that the SSE is often associated temporally and spatially with an increased NVT activity. Comprehensive investigations of NVT and short-term SSE in the subduction zones of Japan and Cascadia supported mainly the hypothesis that both these events are occurring simultaneously, and most likely on the same plate interface [*La Rocca et al.*, 2010; *Obara and Hirose*, 2006; *Obara et al.*, 2004; *Peterson and Christensen*, 2009; *Rogers and Dragert*, 2003]. It results in a view of the problem for which the so called Episodic Tremor and Slip (ETS) events [*Rogers and Dragert*, 2003] are just short-duration SSE and NVT, and are closely associated both in time and space [*Shelly et al.*, 2007; *Wech et al.*, 2009]. The NVT bursts detected by seismometers in Japan probably consist of a large number of small magnitude low frequency earthquakes [*Shelly et al.*, 2006], which combined slip on the fault may contribute additionally to the crustal deformations produced by concurrent slow slip events.

Some observations nevertheless show that SSE and NVT are not systematically associated in the form of ETS. There are examples of NVT episodes happening without any geodetically (GPS) detectable SSE, and the reverse large, long-term SSE not always accompanied by the NVT [*Delahaye et al.*, 2009; *McCaffrey et al.*, 2008]. Unfortunately, and particularly in the regions of steeply dipping subducted slabs, the small magnitude tremor and slow slip events cannot be analyzed in detail. The subduction zone in Central Mexico provides a favorable opportunity for the study of NVT and SSE because of its unusual subhorizontal plate interface and its large periodic slow slip events of M_w~7.5 [*Cotte*, 2009; *Kostoglodov et al.*, 2003].

2. Seismic Data and Analysis

Large SSE in Central Mexico coincidentally occurred in 2006 during the Mezo-America Subduction Experiment (MASE) which provided an important set of seismological data making it possible to assess the properties of NVT in the region (Fig. 1). There were 100 broad-band seismic stations installed approximately every ~6 km along the profile running almost perpendicular to the Pacific coast of Mexico, from Acapulco over 550 km inland [*Kim et al.*, 2010]. Unfortunately, in spite of excellent along profile space resolution of the MASE data those do not provide an adequate 2D coverage for accurate hypocentral estimates [*Payero et al.*, 2008].

The common approach in the NVT research consists in applying different methods of tremor detection with the records of different stations, then merging them for source location [*Kao and Shan*, 2004; *La Rocca et al.*, 2009; *Obara*, 2002; *Shelly et al.*, 2007]. In general, the precise hypocenter estimation of the NVT is still problematic due to the low signal to noise ratio and the lack of identification of coherent seismic phases. In absence of complete set of precise NVT locations a simple way to describe the tremor activity in time is the differential duration of tremor (DDT) episodes (e.g., [*Payero et al.*, 2008; *Shelly et al.*, 2007]) disregarding their amplitudes. The DDT bears also on the NVT intensity with time since the average tremor amplitudes seems to be invariant to the NVT bursts duration [*Aguiar et al.*, 2009].

To avoid the difficulties related to tremor source location from the MASE data and at the same time to characterize their duration and intensity, we apply an “energy” inference [*Kostoglodov et al.*, 2008]. The tremor wave-train develops mainly between 0.5-15 Hz but has the best signal to noise ratio in the 1-2 Hz frequency range at most of the MASE stations (fig. S1). Therefore, the first step in our energy approach is to filter signals between 1 and 2 Hz and to compute their energy (squared velocity). To obtain comparable NVT energy assessments at every seismic station, it is necessary to correct the records for the site effects after individual background noise reduction. The site effects are estimated using the coda calibration method [*Husker et al.*, 2010]. We then apply median filter to smooth the entire waveforms and a threshold cutoff procedure to compile a complete register (a list of initial time and duration) of NVT recorded with the MASE seismic stations for 2005-2007. The NVT register was compiled using the data at 24 MASE stations, which had acceptable signal-to-noise ratio. A space-time distribution of the total NVT radiated energy in 1-2 Hz bandwidth was obtained via integration in time and interpolation in space (Fig 2). It is clearly seen that the NVT seismic energy was radiated to the seismic stations located predominantly above the subhorizontal interplate contact segment, which is at approximately 40 km depth, between 170 and 260 km from the trench. A maximum of the NVT energy attenuation curve (fig. S2) constrains the location of particular tremor bursts train along the MASE profile. Thus, the space distribution of the maximum energy release (Fig. 2) corresponds to the locations of the NVT sources.

3. GPS data modeling

Surface displacements produced by the 2006 slow slip event were measured by permanent GPS stations, most of them located in Guerrero, Central Mexico [*Larson et al.*, 2007a] along the MASE seismic profile (Fig. 1). The largest displacements, up to 4.4 cm, are observed at the coastal area. The onset and duration of the 2006 SSE were estimated by fitting the sigmoid function to the GPS horizontal components records reduced for the inter-SSE trend at each GPS station (Fig. 2). The total final displacements during the SSE with respect to the North America plate were determined (after appending back the trends) as a difference between maximum and minimum of the fitting function. Dislocation models [*Savage*, 1983] that best fit the total final displacements during the 2006 SSE (fig. S3) require that most of the slow slip (with a maximum of about 19 cm) occurred on the transition zone of the plate interface, a segment about 80-90 km long located between the seismogenic coupled zone (45-75 km from the trench), and a presumably freely slipping zone (Fig. 2). The model still acceptably fit the data when the inland tip of the SSE zone expands some 10-15 km more into the NVT source area, but the slip on the downdip dislocation patch in this case should be notably reduced.

It should be noted that the forward static modeling of the final GPS displacements along the 1D transect provides better constraints on transient segments location and the amount of fault slip. An attempt to invert GPS time series of the 2006 SSE [*Larson et al.*, 2007b] using the Network Inversion Filter (NIF, [*Segall and Matthews*, 1997]) allows excessive inland extension of the slow slip on the plate interface due to very poor approximation of the vertical component time series. Modeling the previous 2002 Guerrero

SSE [*Iglesias*, 2004; *Kostoglodov*, 2003; *Yoshioka et al.*, 2004] ascertain that almost total slip was released on the transient segment of subduction interface limited by ~170 km inland from the trench.

4. Results

Fig. 2 summarizes the main results of this study. The energy distribution suggests that the NVT is mainly located within or above the deep free slipping patch of the plate interface (at 170-250 km from the trench). Indeed, the previous study [*Payero et al.*, 2008] analyzed more than one hundred strong individual NVT episodes in Guerrero reported locations of those tremors which coincide with the NVT energy release area and the NVT depths are mostly distributed over the lower continental crust and plate contact zone.

The 2006 SSE transient dislocation is determined immediately updip of this zone, which means that the SSE and NVT are spatially separated. This observation agrees with the SSE and NVT study in Oaxaca, Mexico subduction zone [*Brudzinski et al.*, 2010]. Four large distinct NVT burst episodes occurred during the lone 2006 SSE. Furthermore, there were several comparably long lasting and intensive NVT episodes during the "quiet" epochs when no apparent SSE was detected by GPS (except perhaps a poorly resolved in the GPS time series, short term SSE in March 2005 [*Vergnolle et al.*, 2010]). The lack of simultaneity between NVT and long term SSE suggests that they are not an expression of the same underlying process.

We applied a simple method to evaluate an upper limit of the total seismic energy radiated in all NVT episodes during the 2006 SSE from the estimated ratio of the energy power spectrum in 1-2 Hz band and the total energy of the NVT[1]. If all NVT events were occurring on the same fault (plate interface) coherently with similar seismic slip rakes, then the total fault slip produced by all NVT events during the 2006 SSE would be of order 10^{-3}-10^{-4} cm. This value is negligible compared to the average modeled dislocation (~10 cm) of the SSE. The surface expression of this NVT slip can not be measured by modern GPS technique. As the upper limit of the NVT slip is assessed applying a number of generous assumptions, the real effect can be even smaller. That may explain why GPS data do not exhibit any notable surface displacements produced by large NVT episodes during the inter-SSE epochs. The slip detected during the NVT events in Japan [*Ito et al.*, 2007] by the high sensitivity borehole tiltmeters was apparently produced by concurrent short-term SSE.

Equivalent magnitude of the 2006 SSE (M_W ~7) is more than three orders larger than the magnitude of the NVT episodes (M_E 3.3) occurring during the period of slip. Remarkably, a difference of the same order was reported for the SSE (M_w 6.7) and NVT (M_w 3.7) moment magnitudes estimates in the Cascadia subduction zone [*Kao et al.*, 2009].

Two types of slow slip events reported in southwest Japan subduction zone [*Hirose and Obara*, 2005] are the long-term and short-term SSE, both accompanied by NVT. The source area of the short-term SSE is deeper than that of the long-term SSE [*Ueno*, 2009]. This observation would be congruent with the results of this study if the short-term and small magnitude SSE recently detected in Guerrero [*Vergnolle et al.*, 2010] were occurring in the NVT area of the subduction zone. Reliable modeling of the fault slip locations of these mini-SSE is still problematic because the corresponding displacements recorded by GPS are almost at the noise level of the position time series.

5. Discussion

To date, there are several reliable observations in different subduction zones which suggest the existence of two distinct phenomena: large aseismic slow slip events (SSE) and the NVT episodes. If the NVT is accompanied by the smaller magnitude, short-term SSE occurring in the same area then this combination is considered as the ETS. Long term SSE and NVT recorded in the Mexican subduction zone are separated spatially and are not strictly correlated in time, although the NVT activity is intensified by large SSE. Triggering of NVT by stress transients has been documented [*Rubinstein et al.*, 2007] and the mechanism of this interaction, as well as the origin of SSE and NVT, is still disputable.

There is an obvious progression of seismotectonic segmentation of the subduction plate interface in Mexico (Fig. 2D): the low-temperature, shallow weakly-coupled accretional segment; the seismogenic strongly-coupled section (T~150 C°); then the zone where the transient SSE occur (T ≈170-400 C°); and finally a supposedly "free slipping" zone where NVT are generated (T = 400-500 C°). Each section has its specific elastic strain accumulation and rebound regime with different recurrence times of the events (order of $10\text{-}10^2$ years for the subduction thrust earthquakes, 10^{-1}-10 years for the SSE and days-months for the ETS).

The modeling of the GPS data (Fig. 2 and fig. S3) locates the seismogenic coupled zone at shallow depth, with almost the same width and position as the source area of the 1962 M_w ~7.0 Acapulco earthquake doublet [*Ortiz*, 2000]. The transient SSE segment matches the ultra-slow velocity layer (USL) discovered in Guerrero on the top of the subducting plate [*Song et al.*, 2009], and the tremor generating zone [*Payero et al.*, 2008], corresponds to the higher conductivity area of the continental crust [*Jödicke et al.*, 2006] over the "free-slipping” segment of the plate interface. The free slip condition is only an abstraction used for the SSE modeling. In reality the subducting oceanic plate should interact with the overriding continental plate on this weak interplate segment too, probably though a low viscosity layer [*Hilairet et al.*, 2007; *Kostoglodov*, 1988] similar to the USL, and transmit some shear stress to the upper plate. The accumulated strain in the continental plate may be periodically released by the NVT and small magnitude SSE.

Our observations and modeling results suggest the existence of two essentially different stages in the prograding process of the strain rebound on the downward portion of the subduction plate interface: the SSE and NVT. The SSE doesn't produce seismic radiation (at least above the noise level at current instrumentation) and it is a creep-like slip episode. Slow slip modulates NVT activity by increasing the shear stress and dilatation over the downdip plate interface in the area where appropriate conditions exist for the NVT incidence. Thus, these two phenomena are separated in space and not necessarily consistent in time. Now it is confirmed from a number of observations in different subduction zones including Mexico that some SSE (at least long term events) occur lacking the concurrent detectable tremor at the same area. Nevertheless, based on our results it is not yet clear if the NVT may happen without short term SSEs which are still undetectable by the GPS technique.

Future studies in different subduction zones should verify this hypothesis which is important to understand the origin of the SSE and NVT.

Acknowledgments

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References

Aguiar, A. C., T. I. Melbourne, and C. W. Scrivner (2009), Moment release rate of Cascadia tremor constrained by GPS, *J. Geophys. Res.*, *114*.

Brudzinski, M. R., H. R. Hinojosa-Prieto, K. M. Schlanser, E. Cabral-Cano, A. Arciniega-Ceballos, O. Diaz-Molina, and C. DeMets (2010), Nonvolcanic tremor along the Oaxaca segment of the Middle America subduction zone, *J. Geophys. Res.*, *115*, B00A23.

Cotte, N., A. Walpersdorf, V. Kostoglodov, M. Vergnolle, J.-A. Santiago, I. Manighetti, and M. Campillo (2009), Anticipating the Next Large Silent Earthquake in Mexico, *Eos Trans. AGU*, *90* (21).

Delahaye, E. J., J. Townend, M. E. Reyners, and G. Rogers (2009), Microseismicity but no tremor accompanying slow slip in the Hikurangi subduction zone, New Zealand, *Earth Planet Sc Lett*, *277* (1-2), 21-28.

DeMets, C., R. G. Gordon, D. F. Argus, and S. Stein (1994), Effect of recent revisions to the geomagnetic reversal time scale on estimates of current plate motions, *Geophys. Res. Lett.*, *21*, 2191-2194.

Hilairet, N., B. Reynard, Y. Wang, I. Daniel, S. Merkel, N. Nishiyama, and S. Petitgirard (2007), High-Pressure Creep of Serpentine, Interseismic Deformation, and Initiation of Subduction, *Science*, *318* (5858), 1910-1913.

Hirose, H., and K. Obara (2005), Repeating short- and long-term slow slip events with deep tremor activity around the Bungo channel region, southwest Japan, *Earth Planets Space*, *57*, 961-972.

Husker, A., S. Peyrat, N. Shapiro, and V. Kostoglodov (2010), Automatic non-volcanic tremor detection in the Mexican subduction zone, *Geofis Int*, *49* (1), 17-25.

Iglesias, A., S.K. Singh, A. R. Lowry, M. Santoyo, V. Kostoglodov, K. M. Larson, S.I. Franco-Sánchez and T. Mikumo (2004), The silent earthquake of 2002 in the Guerrero seismic gap, Mexico (Mw=7.4): inversion of slip on the plate interface and some implications, *Geofis Int, 43* (3), 309-317.

Ito, Y., K. Obara, K. Shiomi, S. Sekine, and H. Hirose (2007), Slow Earthquakes Coincident with Episodic Tremors and Slow Slip Events, *Science*, *315* (5811), 503-506.

Jödicke, H., A. Jording, L. Ferrari, J. Arzate, K. Mezger, and L. Rüpke (2006), Fluid release from the subducted Cocos plate and partial melting of the crust deduced from magnetotelluric studies in southern Mexico: Implications for the generation of volcanism and subduction dynamics, *J. Geophys. Res.*, *111*.

Kao, H., and S.-J. Shan (2004), The Source-Scanning Algorithm: mapping the distribution of seismic sources in time and space, *Geophys J Int*, *157* (2), 589-594.

Kao, H., S.-J. Shan, H. Dragert, and G. Rogers (2009), Northern Cascadia episodic tremor and slip: A decade of tremor observations from 1997 to 2007, *J. Geophys. Res.*, *114*.

Kim, Y., R. W. Clayton, and J. M. Jackson (2010), Geometry and seismic properties of the subducting Cocos plate in central Mexico, *J. Geophys. Res.*, *115* (B6), B06310.

Kostoglodov, V. (1988), Sediment Subduction - a Probable Key for Seismicity and Tectonics at Active Plate Boundaries, *Geophys J Int*, *94* (1), 65-72.

Kostoglodov, V., S. K. Singh, J. A. Santiago, S. I. Franco, K. M. Larson, A. R. Lowry, and R. Bilham (2003), A large silent earthquake in the Guerrero seismic gap, Mexico, *Geophys Res Lett*, *30* (15).

Kostoglodov, V., N. Shapiro, K. M. Larson, J. Payero, A. Husker, J. A. Santiago, and R. W. Clayton. (2008), Nonvolcanic Tremor Activity is Highly Correlated With Slow Slip Events, Mexico, in *Eos Trans. AGU, 89(53), Fall Meet. Suppl., Abstract U31B-05*.

La Rocca, M., D. Galluzzo, S. Malone, W. McCausland, and E. Del Pezzo (2010), Array analysis and precise source location of deep tremor in Cascadia, *J. Geophys. Res.*, *115*, B00A20.

La Rocca, M., K. C. Creager, D. Galluzzo, S. Malone, J. E. Vidale, J. R. Sweet, and A. G. Wech (2009), Cascadia Tremor Located Near Plate Interface Constrained by S Minus P Wave Times, *Science*, *323* (5914), 620-623.

Larson, K. M., V. Kostoglodov, S. Miyazaki, and J. A. S. Santiago (2007), The 2006 aseismic slow slip event in Guerrero, Mexico: New results from GPS, *Geophys. Res. Lett.*, *34* (13), 1-5.

Manea, V. C., M. Manea, V. Kostoglodov, C. A. Currie, and G. Sewell (2004), Thermal structure, coupling and metamorphism in the Mexican subduction zone beneath Guerrero, *Geophys J Int*, *158*(2), 775-784.

McCaffrey, R., L. M. Wallace, and J. Beavan (2008), Slow slip and frictional transition at low temperature at the Hikurangi subduction zone, *Nature Geosci, 1* (5), 316-320.

Obara, K. (2002), Nonvolcanic Deep Tremor Associated with Subduction in Southwest Japan, *Science*, *296* (5573), 1679-1681.

Obara, K., and H. Hirose (2006), Non-volcanic deep low-frequency tremors accompanying slow slips in the southwest Japan subduction zone, *Tectonophysics, 417* (1-2), 33-51.

Obara, K., H. Hirose, F. Yamamizu, and K. Kasahara (2004), Episodic slow slip events accompanied by non-volcanic tremors in southwest Japan subduction zone, *Geophys. Res. Lett.*, *31*.

Ortiz, M., S. K. Singh, V. Kostoglodov and J. Pacheco (2000), Source areas of the Acapulco-San Marcos, Mexico earthquakes of 1962 (M 7.1; 7.0) and 1957 (M 7.7), as constrained by tsunami and uplift records, *Geofis Int*, *39* (4), 337-348.

Payero, J. S., V. Kostoglodov, N. Shapiro, T. Mikumo, A. Iglesias, X. Pérez-Campos, and R. W. Clayton (2008), Nonvolcanic tremor observed in the Mexican subduction zone, *Geophys. Res. Lett., 35* (7).

Peterson, C. L., and D. H. Christensen (2009), Possible relationship between nonvolcanic tremor and the 1998–2001 slow slip event, south central Alaska, *J. Geophys. Res.*, *114*.

Rogers, G., and H. Dragert (2003), Episodic Tremor and Slip on the Cascadia Subduction Zone: The Chatter of Silent Slip, *Science*, *300* (5627), 1942-1943.

Rubinstein, J. L., D. R.Shelly, and W. L.Ellsworth (2010), Non-volcanic tremor: A window into the roots of fault zones, in *New Frontiers in Integrated Solid Earth Sciences*, edited by S. Cloetingh and J. Negendank, pp. 287-314, Springer Science + Business Media B.V.

Rubinstein, J. L., J. E. Vidale, J. Gomberg, P. Bodin, K. C. Creager, and S. D. Malone (2007), Non-volcanic tremor driven by large transient shear stresses, *Nature*, *448* (7153), 579-582.

Savage, J. C. (1983), A Dislocation Model of Strain Accumulation and Release at a Subduction Zone, *J. Geophys. Res.*, *88* (B6), 4984-4996.

Schwartz, S. Y., and J. M. Rokosky (2007), Slow slip events and seismic tremor at circum-Pacific subduction zones, *Rev. Geophys.*, *45*.

Segall, P., and M. Matthews (1997), Time dependent inversion of geodetic data, *J. Geophys. Res.*, *102* (B10), 22391-22409.

Shelly, D. R., G. C. Beroza, and S. Ide (2007), Non-volcanic tremor and low-frequency earthquake swarms, *Nature*, *446* (7133), 305-307.

Shelly, D. R., G. C. Beroza, S. Ide, and S. Nakamula (2006), Low-frequency earthquakes in Shikoku, Japan, and their relationship to episodic tremor and slip, *Nature*, *442* (7099), 188-191.

Song, T.-R. A., D. V. Helmberger, M. R. Brudzinski, R. W. Clayton, P. Davis, X. Perez-Campos, and S. K. Singh (2009), Subducting Slab Ultra-Slow Velocity Layer Coincident with Silent Earthquakes in Southern Mexico, *Science*, *324* (5926), 502-506.

Ueno, T., T. Takeda, K. Obara, and Y. Asano (2009), Seismic explosion survey around slow events in the Tokai region, Japan, in *Eos, Vol. 90, Number 52, 29 December 2009, Fall Meet. Suppl., Abstract T11C-1837*.

Vergnolle, M., A. Walpersdorf, V. Kostoglodov, P. Tregoning, J. A. Santiago, N. Cotte, and S. I. Franco (2010), Slow slip events in Mexico revised from the processing of 11 year GPS observations, *J. Geophys. Res.*, *115* (B8), B08403.

Wech, A. G., K. C. Creager, and T. I. Melbourne (2009), Seismic and geodetic constraints on Cascadia slow slip, *J. Geophys. Res.*, *114*.

Yoshioka, S., T. Mikumo, V. Kostoglodov, K. M. Larson, A. R. Lowry, and S. K. Singh (2004), Interplate coupling and a recent aseismic slow slip event in the Guerrero seismic gap of the Mexican subduction zone, as deduced from GPS data inversion using a Bayesian information criterion, *Phys Earth Planet In*, *146* (3-4), 513-530.

[1]Axiliary materials are available in the HTML doi: …

Figure captions

Figure 1. Central Mexico study area (inset). Triangles show positions of permanent GPS stations. Blue vectors are velocities (mm/year) of secular motion of the GPS stations and red vectors are total displacements (mm) produced by 2006 SSE. Small green squares show locations of the MASE broad band seismic stations used for this study. MAT – Middle America Trench shown by dashed line. Thick annotated arrows represent the convergence rate between the Cocos and North America plates [*DeMets et al*., 1994]. All displacements and velocities are shown with respect to the fixed North America plate. 2006 SSE displacement at ZIHP is almost zero. LAZA station was installed during the SSE and did not record a complete slow slip displacement.

Figure 2. A – Time distribution of all the (1-2 Hz) NVT seismic energy recorded during the MASE experiment. B – Time-Distance distribution of the NVT energy (average smoothing with the moving time window of 15 days) along the MASE profile. Red triangles indicate locations of seismic stations. C – Daily time series at MEZC GPS station located approximately in the middle of the MASE profile. SN, WE – South-North and West-East components, respectively. SSE-2006 annotated rectangle delimits the period of the 2006 slow slip event. D – Subducting Cocos - North America plates interface in the study area according to [*Kim et al.*, 2010]. The background image is a resistivity model [*Jödicke et al.*, 2006]. Inverted pink triangles are annotated with the temperature °C which is modeled on the plate interface [*Manea et al*., 2004]. Green antenna-like symbols show projections of the GPS stations locations on the MACE transect. Panels A-C have the same time scale.

Panels B and D are aligned so that the zone where tremor was detected can be compared to the plate configuration.

Figure 1.

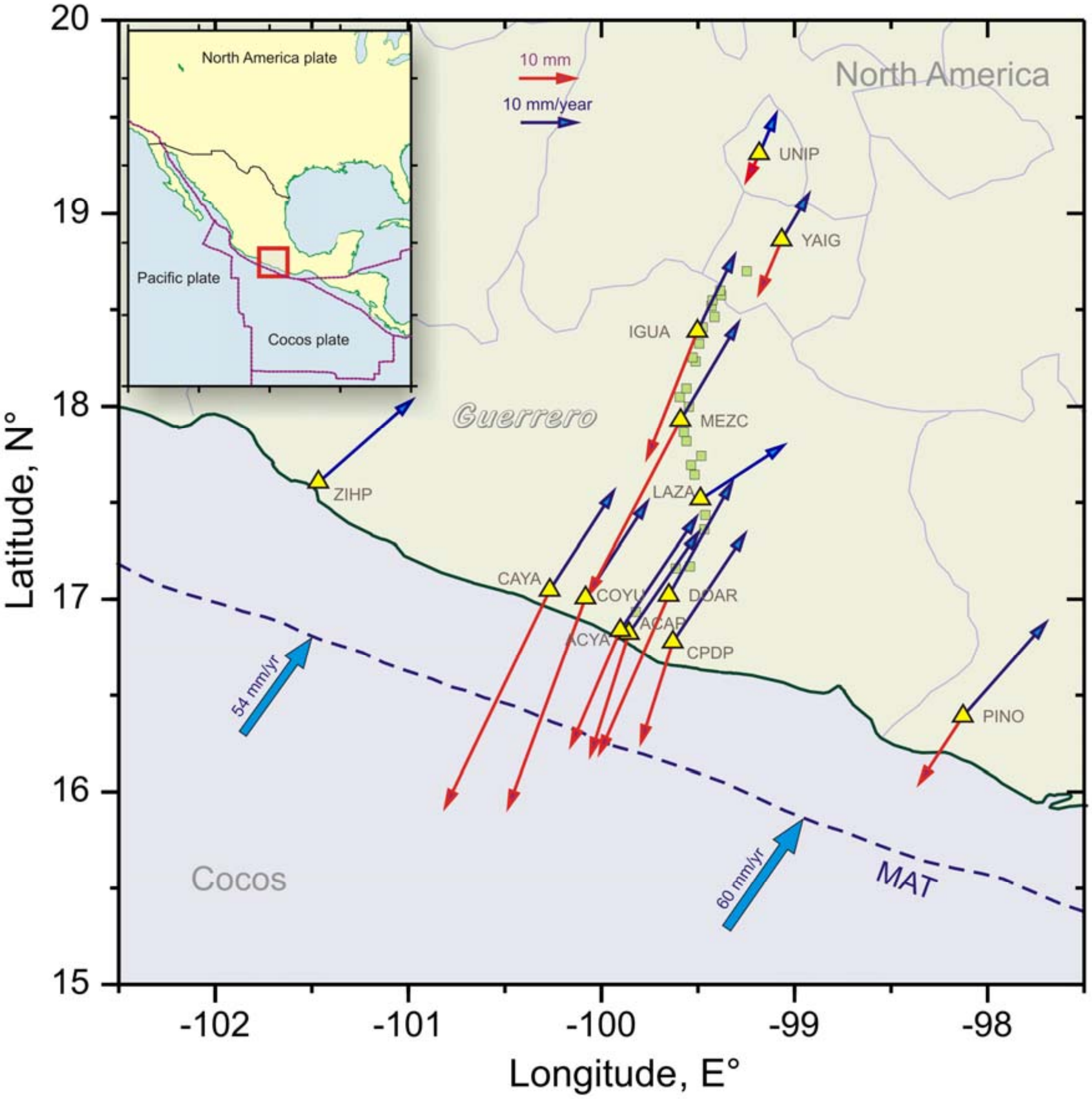
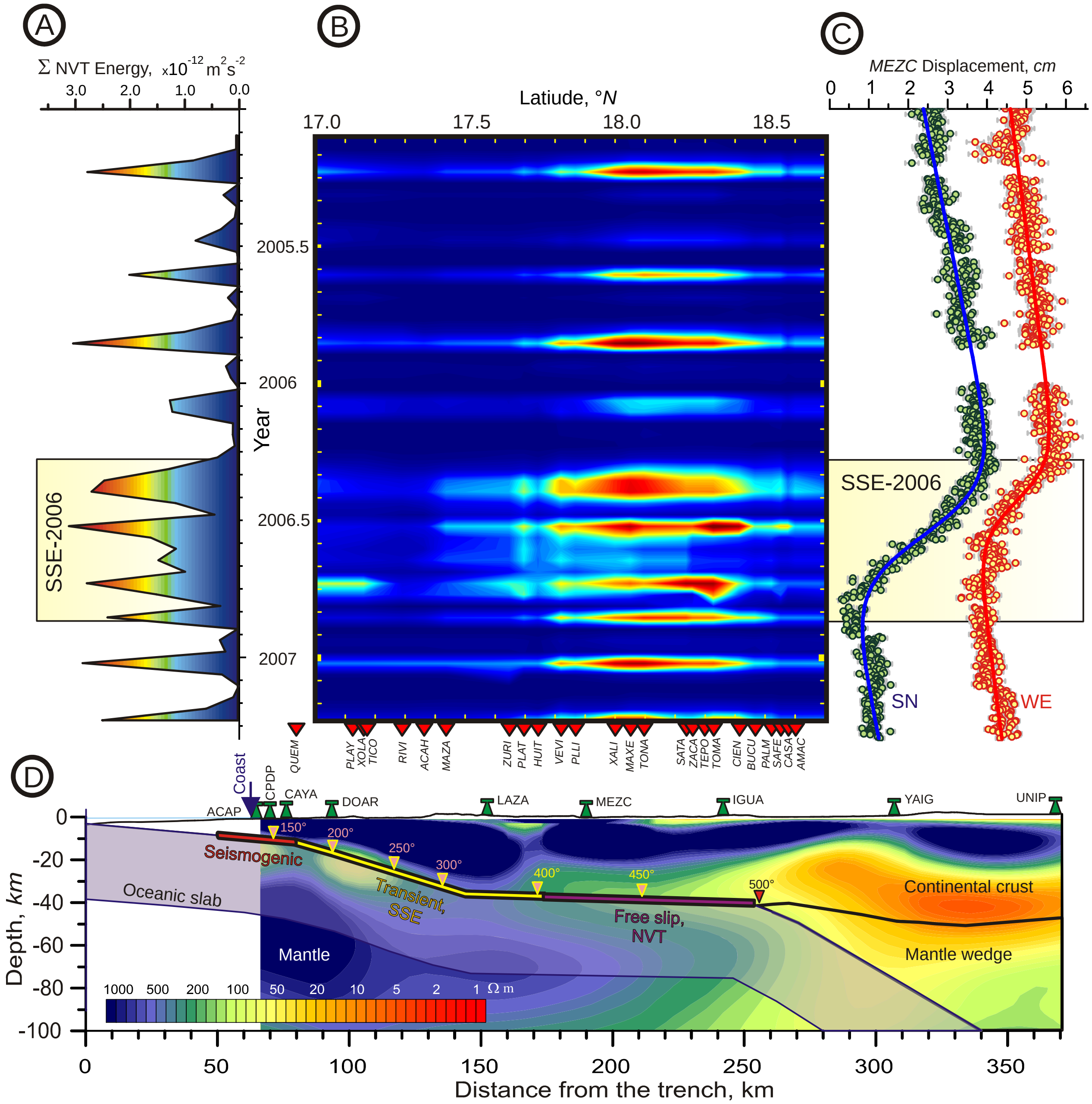

20
19
18
17
16
15
-102
-101
-100
-99
-98
Latitude, N°
Longitude, E°
North America plate
Pacific plate
Cocos plate
10 mm
10 mm/year
North America
UNIP
YAIG
IGUA
MEZC
Guerrero
ZIHP
LAZA
CAYA
COYU
DOAR
ACAP
ACYA
CPDP
PINO
54 mm/yr
60 mm/yr
MAT
Cocos

Figure 2.



A
Σ NVT Energy, x10^-12 m^2 s^-2
3.0 2.0 1.0 0.0
SSE-2006
B
Latiude, °N
17.0 17.5 18.0 18.5
2005.5
2006
2006.5
2007
Year
QUEM PLAY XOLA TICO RIVI ACAH MAZA ZURI PLAT HUIT VEVI PLLI XALI MAXE TONA SATA ZACA TEPO TOMA CIEN BUCU PALM SAFE CASA AMAC
C
MEZC Displacement, cm
0 1 2 3 4 5 6
SSE-2006
SN
WE
D
Coast
ACAP CPDP CAYA DOAR LAZA MEZC IGUA YAIG UNIP
150° 200° 250° 300° 400° 450° 500°
Seismogenic
Transient, SSE
Free slip, NVT
Oceanic slab
Mantle
Continental crust
Mantle wedge
1000 500 200 100 50 20 10 5 2 1 Ω m
Depth, km
0 -20 -40 -60 -80 -100
0 50 100 150 200 250 300 350
Distance from the trench, km